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OVERVIEW OF ASTM SYMPOSIUM ON ANALYTICAL AND EXPERIMENTAL METHODS FOR RESIDUAL STRESS EFFECTS IN FATIGUE

R. L. CHAMPOUX

J. H. UNDERWOOD

J. A. KAPP

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US ARMY ARMAMENT RESEARCH,
DEVELOPMENT AND ENGINEERING CENTER
CLOSE COMBAT ARMAMENTS CENTER
BENÉT LABORATORIES
WATERVLIET, N.Y. 12189-4050

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An overview of the ASTM Symposium on Analytical and Experimental Methods for Residual Stress Effects in Fatigue, held on 20-21 October 1986 in Phoenix, Arizona, is presented. The background and objective for the symposium are described and the technical papers presented at the symposium and published in the proceedings are summarized. The papers are in two general categories: (1) effects of residual stress near the surface of a specimen or component--particularly shot peening applications, and (2) effects of bulk residual stresses--particularly autofrettaged pressure vessels and piping.

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7. AUTHORS (Cont'd)

R. L. Champoux
Ceramic Binder Systems, Inc.
Butte, MT 59701

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INTRODUCTION

Producing beneficial compressive residual stresses on the surface or interior of a structural component has been known for many years to increase service life. Conversely, it is also well known that tensile residual stresses reduce life. Application examples of beneficial residual stresses are shot peening of springs and other components subjected to cyclic loading, cold expansion of fastener holes, and autofrettage of pressure vessels and piping. On the negative side, welding, heat treating, and metal forming, if carelessly done, can produce tensile residual stresses which could lead to premature failure.

Much attention has been given to residual stress in the testing and analysis of structural materials and components because of both the beneficial and detrimental effects. Measurements of service life with residual stress present and measurements of the amount of residual stress have been common topics of study in symposia and technical publications of ASTM and other technical groups. However, the topic here--determining through analyses and experiments the effects of residual stress on fatigue behavior--has not received much attention. The amount of stress present and the resulting life has been measured, but the understanding of the mechanisms and mechanics which control the increases or decreases in fatigue life has not been sufficiently addressed. An improved understanding in this area will lead to quantitative descriptions and, hopefully, predictions of safe service lives for structures containing residual stresses. Since most structural materials do contain residual stresses to some extent, reliable descriptions of their effects will be quite useful.

SUMMARY OF SYMPOSIUM

A Special Technical Publication (STP) was published as a result of the October 1986 Symposium on Analytical and Experimental Methods for Residual Stress Effects in Fatigue, held in Phoenix, Arizona, 20-21 October 1986 (ref 1). The purpose of the publication and symposium was to gain a better understanding of residual stress effects in fatigue and to communicate the current efforts in this area to the technical community. The symposium was organized by ASTM Committee E-9 on Fatigue and its Subcommittee E09.02 on Residual Stress Effects in Fatigue for the purposes above and also to address future standard test and analysis methods in this area.

Sixteen papers were presented at the symposium, and due to the usual effects of deadlines and peer review, eleven appeared in the STP. The titles and authors of the papers are as follows:

- Residual Stress Effects on Fatigue of Surface Processed Steels--Ronald W. Landgraf and Russell A. Chernenkoff
- Approximate Analysis for Optimizing Prestress Treatments--H. O. Fuchs
- The Effect of Elevated Temperature on Shot Peened 403 Stainless Steel--William H. Childs
- X-ray Diffraction and Acoustic Emission Study of Fatigue Damage in Aluminum Alloys--Claude Bathias, J. P. Bonnafe, J. L. Lebrun, and G. Maeder
- Stress Intensity Factors Caused by Residual Stress Fields in Autofrettaged Tubing--Alexander Stacey and George A. Webster
- On Fatigue Life Calculation in Thick-Walled Cylinders With Complex Residual Stresses--San-Li Pu and Peter C. T. Chen

[1]R. L. Champoux, J. H. Underwood, and J. A. Kapp, eds., Analytical and Experimental Methods for Residual Stress Effects in Fatigue, ASTM STP 1004, American Society for Testing and Materials, Philadelphia, 1988.

- Analysis of a Notched Four-Point Bending Sample Containing Various Residual Stresses--Joseph A. Kapp and Alexander Stacey
- Fatigue Crack Propagation and Residual Stress in a Quenched and Tempered C-Mn-B Steel--A. John Fletcher, W. Geary, and Julia E. King
- Increased Pressure Vessel Fatigue Life Caused by Decreased Autofrettage--Bruce B. Brown
- Influence of Residual Stress on Fatigue Crack Growth in Thick-Walled Cylinders--Alexander Stacey and George A. Webster
- Estimating Residual Stresses and Their Effect in Welded Aluminum Components in Fatigue--Dimitris Kosteas

The papers can be discussed in two groups: (1) those dealing primarily with effects of residual stresses near surfaces, and (2) those dealing with through-thickness or bulk effects. Of course there is some overlap, some of it intentional, in order to develop methods of analysis which describe both surface and bulk effects. Surface effects deal mainly with shot peening applications, and bulk effects with pressure vessel and piping applications. Heat-treat stresses are considered as both surface and bulk effects.

There is some balance in the publication, even though there is not a large number of papers. All but one of the applications mentioned above are addressed. Cold forming of holes is not directly covered, but the several papers on autofrettaged cylinders involve similar geometry and methods of analysis. Aluminum alloys are addressed in only two papers, but this is because the majority of applications are with steel.

A description of the symposium papers is given in the following sections, under the categories of surface effects and bulk effects.

SURFACE EFFECTS OF RESIDUAL STRESS

The first two papers in the publication include reviews of the methods used for analysis of residual stress effects at surfaces and research results in this area. The Landgraf and Chernenkoff paper addressed stress patterns arising from shot peening and induction hardening of steels. They developed criteria to predict crack growth, stress relaxation, and fatigue life for prescribed conditions and then compared their predictions with results from the literature. Fuchs described a method of analysis for obtaining optimum shot peening conditions for a given component and applied loading. He checked the results of the analysis with experimental results from a notched steel specimen loaded in rotating bending.

The second two papers in this section on surface effects are primarily experimental in nature. Childs performed tests to answer the difficult question of residual stress loss due to exposure at elevated temperatures. He found that shot peened 403 stainless steel lost a significant amount of compressive stress at temperatures as low at 300°F. Bathias et al. performed a comprehensive experimental study of the near-surface residual stresses in 2024-T3 and 7075-T7 aluminum alloys using x-ray diffraction and a parallel study of the stages of crack initiation and growth in the same materials. Relating the stress details to the stages of growth, the authors were able to draw conclusions regarding fatigue mechanisms as affected by residual stress.

BULK EFFECTS OF RESIDUAL STRESS

The first two papers in the general category of bulk effects are primarily analytical studies of thick-walled cylinders, addressing the practical application of autofrettaged pressure vessels and piping. Stacey and Webster used boundary integrals and weight functions to calculate a stress intensity factor due to the residual stress field through the full wall thickness of the cylinder. Results from the two methods of analysis and from experimental measurements are all in good agreement. Pu and Chen calculated fatigue lives for cylinders containing residual stress based on stress intensity factor results from prior analyses. Modifying these stress intensity factors, they obtained good agreement with fatigue lives from the literature for A723 steel cylinders.

Kapp and Stacey reported the results of an analytical round robin program to predict the fatigue life of notched four-point bend specimens of A723 steel. Both bulk and surface residual stress effects were considered by producing stresses in baseline specimens subjected to bulk specimen plastic deformation and surface shot peening. Stress distributions were calculated for both types of effects, and fatigue lives were predicted and compared with baseline test results.

Bulk effects due to heat treatment of a steel and welding of an aluminum alloy were considered by Fletcher et al. and Kosteas, respectively. The steel was a carbon-manganese-boron composition used for haulage chain that was found to contain tensile residual stresses near the surface and compressive stresses in the interior. The stresses were caused by the transformation volume changes

during the quench. The 7020 aluminum studied by Kosteas was in relation to a research program on welded aluminum beams. Analyses of residual stresses and their effect on the fatigue behavior of welded aluminum structures were reviewed in general, and specific fatigue strength data of welded specimens were reported.

Two additional papers on residual stress effects in thick-walled cylinders complete the publication. Brown reported results from A723 steel cylinders with varying amounts of autofrettage residual stress. An optimum residual stress distribution was found, one in which fatigue failure occurred at about the same number of cycles on the inner and outer surfaces of the cylinder. Stacey and Webster, in their second paper in the publication, described the results of ring samples cut from steel tubing which contained residual stresses. By taking into account the differences between the ring specimens and the actual tubing as loaded in service, the authors found significant reductions in fatigue crack growth rates due to compressive residual stresses.

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1. R. L. Champoux, J. H. Underwood, and J. A. Kapp, eds., Analytical and Experimental Methods for Residual Stress Effects in Fatigue, ASTM STP 1004, American Society for Testing and Materials, Philadelphia, 1988.

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